Recent Developments in the Improved Ship Structures Maintenance Management (ISSMM) Project

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Abstract

The Improved Ship Structural Maintenance Management (ISSMM) project was initiated by the Canadian Department of National Defence (DND) in 1996 to provide a validated tool for engineers to use in making rational assessments of the effects of degradation and damage on a ship's structural capability to undertake a given mission. The project encompasses the integration of modern sea load prediction methods, finite element models, fatigue and ultimate strength analysis and an extensive data management system into an engineering software tool. ISSMM is the largest project involving ship structures R&D in Canada, with some components being used by and supported by other nations.

This paper discusses recent progress on ISSMM including the development of structural sea load cases from defined operational profiles, validation of load and response prediction methods via sea trials, an improved method for efficient production of detail finite element models, the object-oriented ship database management system developed for ISSMM, and the integration of load prediction codes and ultimate strength evaluation modules with structural finite element analysis. Example problems of the effects of corrosion on strength and of crack propagation will be discussed.

Introduction

The Canadian Navy has initiated improvements to its maintenance practices for naval vessels through a program entitled the Naval Ship Maintenance Program (NSMP). The NSMP encompasses new survey and repair procedures and guidelines, a computer database to track inspection and repair actions (Structural Inspection Database - SID), and a process for certifying the structural integrity of each vessel (Ship Structural Integrity Program - SSIP). An inherent requirement of this overall program is the need to determine the structural capability of the vessel in its current condition to meet its operational requirements. To meet this need, DND initiated a major development project, ISSMM (Improved Ship Structural Maintenance Management), to develop an integrated computer-based approach using modern methods of analysis, to efficiently assess the change in structural integrity of a Canadian Forces vessel due to damage or degradation. The ISSMM project was initiated in April 1996 after a three-year concept planning stage [1,2,3,4,5].

The planning stage was followed by proof of concept studies, the advancement of most of the application tools for specific types of structural and sea loads analyses and the initiation of material and structural databases. Initial developments of an integrated hierarchical object-oriented data (HOOD) management system for ship structures have also been undertaken by Defence Research Establishment Atlantic (DREA) to provide a framework for the overall software development and integration. The next step in the development of ISSMM is to produce the overall software package that will complete the development of, and integration of, the required analysis functions and their necessary databases. This paper summarizes recent progress and future plans in the development of sea load applications and structural integrity assessment for the ISSMM project.

Classical rules-based ship structural design and analysis methods do not lend themselves to determination of the operational structural integrity of an in-service vessel in a degraded condition. Recent advances in structural analysis technology such as the finite element method, 3-D panel methods for sea loads, ultimate strength programs, fatigue and fracture assessment methods, and the rapid advancements in computing technology, have made it possible to develop an integrated method to evaluate the structural capability of a vessel, including the effects of degradation. The goal of the ISSMM project is to make this technology readily and effectively accessible to the CF naval architecture and marine engineering community. A flow chart of the different modules of the ISSMM program is given in Figure 1.

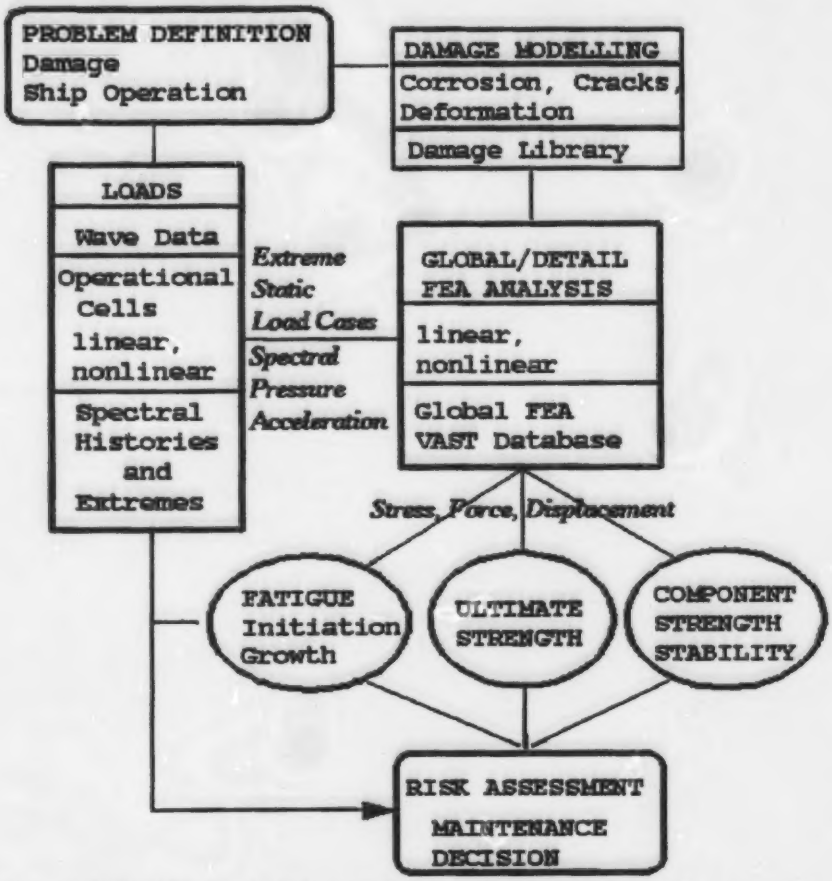

Figure 1: ISSMM Flowchart of Program Functional Requirements

The flowchart outlines the basic functionality of the ISSMM software. The process is initiated by defining the ship, the damage and the intended operation of the vessel. This information is used to progress to the definition of structural sea loads to be used in the assessment and to create structural models incorporating the damage. Finite element analysis is used to translate the structural sea loads into load effects for the damaged and undamaged vessel and these load effects are used in the assessment of structural integrity through fatigue, ultimate strength and component strength and stability failure limit states. These failure limit states are then used to aid the operator in a risk assessment and to evaluate repair and operational alternatives.

Software Development Environment

The software tool produced by the ISSMM project is to be used by Naval Architects and Engineers residing in the Directorate of Maritime Ship Support (DMSS) and the Fleet Maintenance Facilities on each coast, and by contractors in support roles for the Halifax Class. While the user is expected to be knowledgeable and competent in the field of ship structures and maintenance and repair strategies, the user is not expected to be expert in applying finite element analysis, advanced sea load codes, fracture mechanics or reliability methods to ship structures.

Initial development plans for ISSMM [1] which were undertaken in the early 1990's envisioned the need for a high level work station to meet the computing requirements. Since that time, developments have

made it practical to undertake the ISSMM development on a PC. Given that ISSMM is supposed to be a rapid engineering assessment tool, any conceived ISSMM problem solution should take no more than 4 hours from problem definition to a risk assessment result, with most problems taking less than one hour.

The ISSMM software tool will consist of a central software module which will interface with various types of analysis codes through a hierarchical object-oriented data (HOOD) management system. The central software module will be developed in an object-oriented approach using an object library, which will allow object re-use. This methodology follows a "Domain Engineering" approach to software development.

The ISSMM software tool will be developed using the Visual C++ and Microsoft Foundation Class (MFC) user interface environment. This will include pull-down menus, on-line help, 3-D graphics visualization and allow the user to undertake the full ISSMM analysis within the operating shell. Examples of two existing user shells developed as part of the ISSMM concept phase are shown in Figure 3.

Halifax Class Database

Developing a software tool that will rapidly undertake a variety of complex analysis tasks on a ship structure is a challenge. Inherent in this process is the need to minimize user data input. The program must contain as complete a database as possible for the Halifax Class structure, connection types, materials, loads, operations, existing analysis models, etc. and be 'smart' in that the program will know when it needs the data and where to get it from.

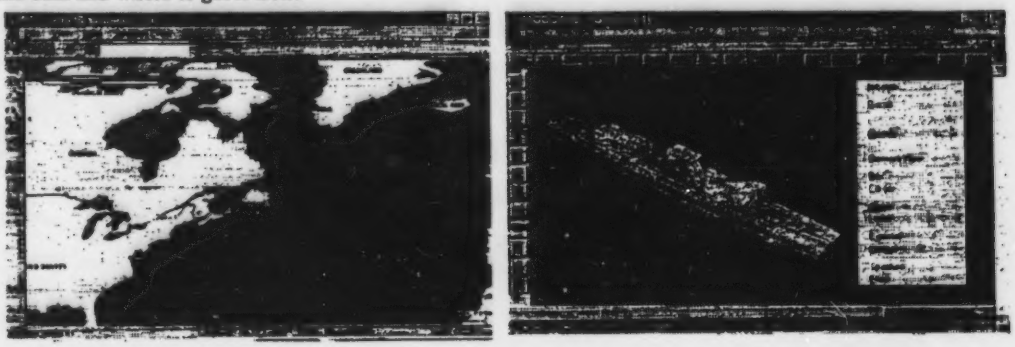

Figure 3: Existing Operating Shell GUIs for Sea Loads Definition (right) and Structural Analysis (left)

The basic data structure will be a geometric database of the Halifax Class. This level will be managed by various data managers and contain all structural and materials information for all levels of the ship from decks and bulkheads down to individual
structural detail connections. Figure 4 shows a partial geometric database for the Halifax class with some of the associated data managers.

The finite element method (FEM) will be used to undertake the structural analysis of the global ship structure and of structural details. A means to create the necessary finite element (FE) models from the geometric database will be developed. Any FE models that are produced for ISSMM or during the use of ISSMM will be stored with reference to the main geometric HOOD database so that the models can easily be retrieved for future use or modification.

As part of the initial work for ISSMM, material testing on the two base metals (A517 and 350WT) and 3 weld metals were undertaken. This data is given in reference [6]. Material data for elastic, plastic and fracture mechanics analysis have been developed and documented. The material data is to be stored in the overall HOOD geometric database and used through a material data manager.

```
#HOOD V1.0 ascii
Separator {
   WWWInLine { name "cpfLOFMan.mod"          }
   WWWInLine { name "cpfStationMan.mod"      }
   WWWInLine { name "cpfCamberDeckMan.mod" }
   WWWInLine { name "cpfDeckMan.mod"     }
   WWWInLine { name "cpfTvBhMan.mod"     }
   WWWInLine { name "cpfLongXYZ.mod"     }
}
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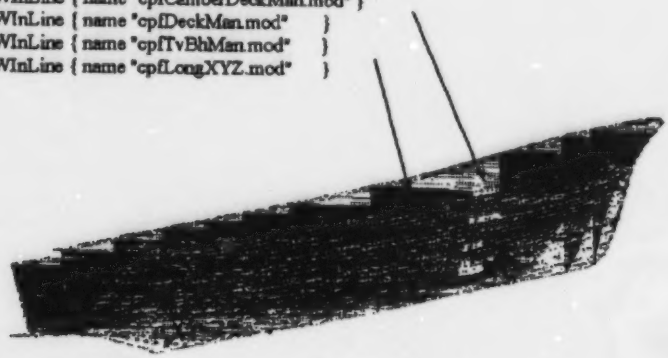

Figure 4: Existing HOOD Data Manager for the Halifax Class

Operational Sea Loads

The sea loads algorithms in ISSMM will develop realistic load cases which are representative of CF ship operational scenarios (short and long term) for use in structural integrity assessment. Ship operational profiles will be described in terms of the time spent in various operational cells that are a function of significant wave height, wave period, ship speed, heading to waves, and ship displacement. For each operational cell, the necessary load effects will be determined including hogging, sagging and lateral bending moments, shear forces, accelerations, hull pressures and still water bending moments. The operational cells will be populated by linear response amplitude operators (RAOs) and, if possible, nonlinear seakeeping analyses. The operational profile load data will be derived by a weighted combination of the various individual cells to give extreme and cumulative loads for ISSMM analysis of the defined operation. Figure 3 (left) showed the current loads shell (GUI) prototype.

Two codes have been used in ISSMM concept studies for developing the necessary linear load data for the operational cells. The first is the 2-D strip theory code SHIPMO7 [7] which can supply bending moments, shears and accelerations. The second code is the three dimensional frequency domain potential flow code PRECAL [8] which can supply bending moments, shears, accelerations and hull pressure spectra. Sea trials [9] have been undertaken to validate the load prediction methods used for ISSMM concept development studies. The British Maritime Technology (BMT) wave statistics package [10] has been purchased for use in ISSMM and is being included via interface to the loads operational profile shell.

Global/Detail Structural Analysis

The FEA will use a global coarse mesh model of the entire ship combined with fine mesh models of specific areas of interest. The fine mesh model will be incorporated into the coarse mesh model by a top-down approach where displacement boundary conditions are derived from the global coarse mesh model and applied to a separate finite element model of the structural detail. Figure 5 shows a detail model of the midship main deck and longitudinal bulkhead structure with part of a global model of the Halifax Class hull. The detail mesh is created with common boundary nodes to the global model. It is essential that the global analysis and load application be done automatically for the user. The user will only have to specify the desired operational scenario and the necessary global finite element analysis will be automatically undertaken. The ISSMM software will produce a global finite element model of the Halifax Class from the

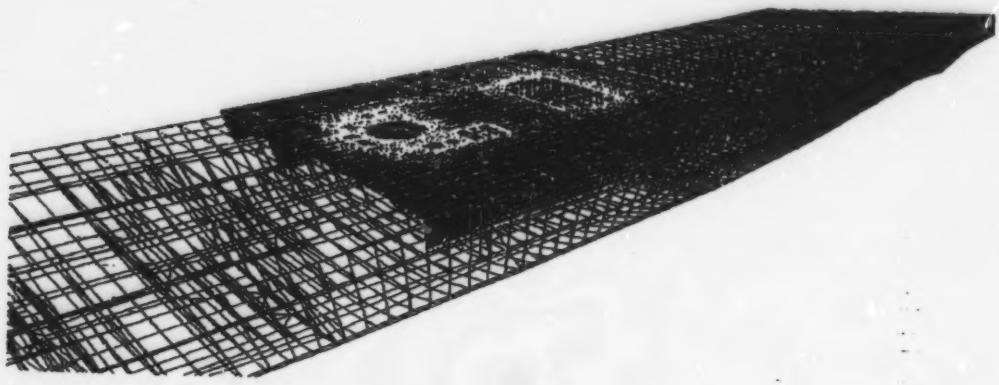

Figure 5: Detail Model of Halifax Class Midship Region in Top-Down Analysis

information stored in the geometric ship database and HOOD data management system. The global model will include all shell plating, decks, longitudinals and transverse bulkheads, superstructure, frames, longitudinal stiffeners, superstructure, tanks, floors, material data and weight distribution. A means to automatically update and track changes to the model through the geometric data management system will also be created. A MAESTRO [11] finite element model of the Halifax Class has been previously developed (it is shown in Figure 3). The Maestro model is not adequate for the purposes of ISSMM as it lacks the hierarchical relational requirements to produce both global and detail models.

Ships are usually built to a defined set of details which are documented by classification societies, owners (such as Navies), or the builders. These defined details include stringer and frame intersections, bulkhead and stiffener connections (watertight and non-watertight), penetrations, cutouts, etc. Thirty common structural detail classes have been identified and developed for the Halifax Class frigate [12]. Parametric stress analyses of the detail classes have been undertaken to produce the best predefined set of nodal distributions for meshing the details. The detail FE models have been created through a specialized detail-object meshing algorithm developed by DREA called DASS (Detail Analysis of Ship Structure) [13,14]. DASS was created to reduce the time to produce validated ship structural detail models to minutes instead of the days that are presently required using general purpose FE meshers. Figure 5 shows two detail meshes resulting from the Halifax Class detail meshing approach for ISSMM.

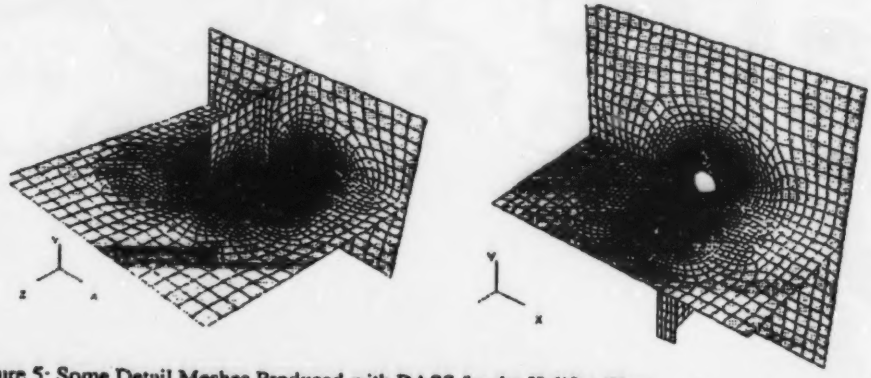

Figure 5: Some Detail Meshes Produced with DASS for the Halifax Class

Much of the preliminary work for ISSMM involving top-down FEA has been undertaken in a program called MGDSA [15] which is an analysis shell (shown in Figure 3-right) which facilitates FE analysis of ship structure. It was originally developed for MAESTRO and VAST [16] models but has expanded to include other FE codes. In general, MGDSA analysis and data management is at a level which is more user intensive than what is required for ISSMM.

Damage Modelling and Analysis

The main objective of ISSMM is to assess the effect of damage on the structural integrity and operational capability of a CF vessel. The methods of determining the loads that a vessel will see during a specific operation and of assessing its structural integrity, are approximate in that they involve some uncertainty and use numerical methods which are not exact. The assessment of the effects of damage will therefore be done as a comparison of the damaged case against the undamaged case for the given operation. This approach will reduce the uncertainties and approximations in the analysis to the greatest extent possible. Damage will be incorporated into the structural models and evaluated against the fatigue, ultimate strength and component failure modes. The damage cases to be considered in ISSMM are described below.

Cracks: The propagation of detected cracks will be investigated as well as the effect of loss of structural continuity on ultimate strength and component failures. Fatigue cracks will be modelled with finite elements which, in conjunction with a crack growth algorithm, will be incrementally remeshed to reflect the new crack length and location of the crack tip. Figure 6 shows an example of a crack meshed in the midship sheer strake region of the Halifax Class. This example is one of several being used to investigate critical crack lengths for various ship operations.

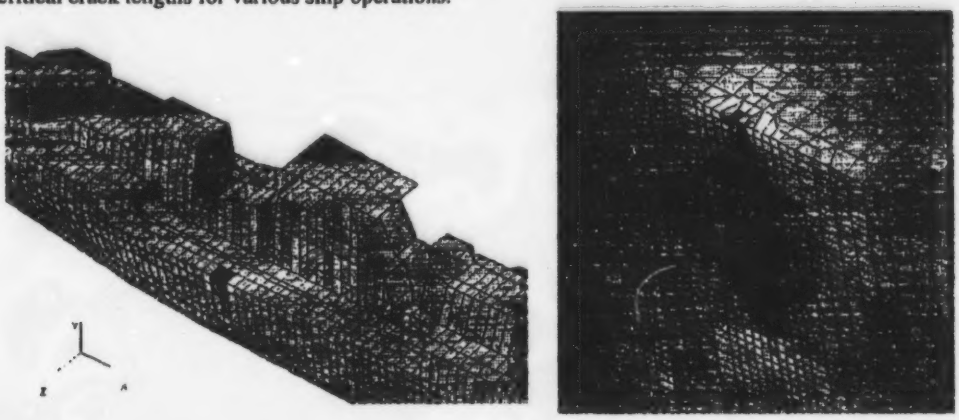

Figure 6: Example of A Crack Meshed into the Sheer Strake of the Halifax Class

Corrosion: The effect of loss of cross sectional area on component strength and stability and on the hull girder ultimate strength will be investigated. Corroded areas which result in high stress concentrations will be investigated for possible crack initiation and subsequent propagation during the operation. Both the extent of the corrosion and the pattern will affect the structural response. The pattern of the corrosion could induce buckling modes of similar configuration. Figure 7 shows an example of the concept studies being undertaken to determine the effects of a corroded region on the Halifax Class on various failure limit states.

Deformation (Dents): The effect of changes in geometry caused by dents in the structure on component failure will be investigated. The effect of imperfections produced by dents on component load-shortening curves will be considered in terms of component failure and hull girder ultimate strength. Deformations which result in high stress concentrations will be investigated for possible crack initiation and subsequent propagation during the operation. When the deformation has been well defined through measurements, an option to adjust the finite element model to match the measured shape will be created. Where deformation is only known in a general sense such as maximum deformation and the extent of the damaged region, a generic modeller using algebraic functions will be employed.

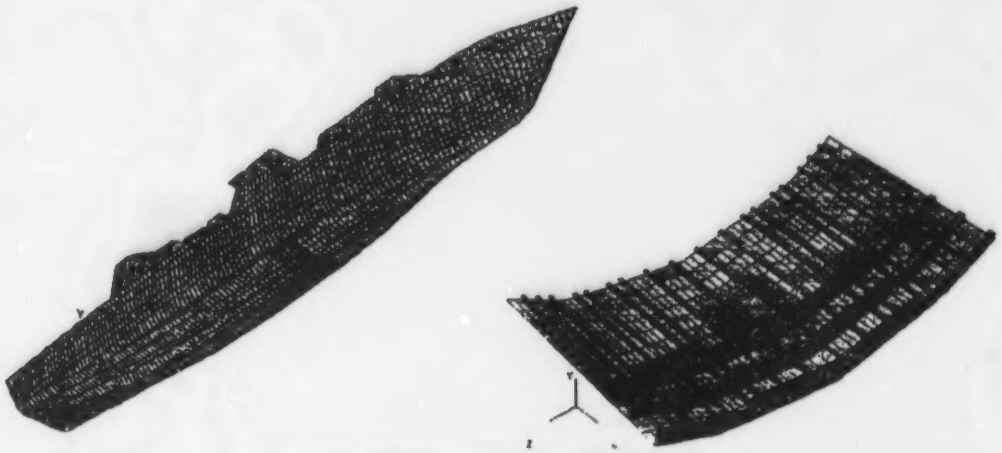

Figure 7: Simulation of Corrosion Damage Modelled in the Halifax Class

Loss of Structure: Damage cases (possibly weapons or severe collisions) which result in loss of part of the structure will be modelled by removing components of the structural models. The effect of loss of structure on ultimate strength and on load distribution for component strength will be evaluated. Structural discontinuities which may result in high stress concentrations will be investigated for possible crack initiation and subsequent propagation during the operation. In addition to the effect of loss of structure on section properties, the possibility of fatigue cracks initiating and propagating from areas of high stress concentration in the damaged area needs to be considered. In cases where significant portions of structure have been lost such as the entire bow, it will be necessary to re-evaluate the hydrodynamic performance of the vessel. Figure 8 shows an example of major loss of structure from collision damage. It will also be necessary to modify the global structural model to determine the redistribution of forces through the structure.

Figure 8: Major Loss of Structure from Collision Damage (courtesy of U.K. MOD)

Ultimate Strength Assessment

The ultimate strength analysis in ISSMM will determine the ultimate strength resistance of damaged and undamaged hull cross-sections for comparison to the expected extreme bending moment value for that section derived for the intended ship operation. Two programs, ULTMAT [17] and FABSTRAN/NS94

[18,19], have been used for hull girder ultimate strength calculations in DND. The geometry of the cross section of interest and the elasto-plastic axial deformation characteristics of individual stiffened plate components which make up the cross section are required for these programs. The elasto-plastic characteristics of the individual stiffened plate components (load-shortening curves) will be generated from nonlinear finite element. The necessary input data to the ultimate strength calculations will be automatically derived from the Halifax Class global database and data management system including the nonlinear elasto-plastic material behaviour. Figure 9 shows a typical ship cross section undergoing an ultimate strength collapse with the deck in compression.

Figure 9: Typical Ship Cross-Section Undergoing Ultimate Strength Collapse

Fatigue Crack Assessment

ISSMM will require the development of, the integration of, and the validation of methods to assess structural fatigue crack initiation and growth. This will include both the probability of a crack initiating in an area of identified large stress concentration (possibly as a result of damage) and the probability of a detected crack propagating during a defined operation. Both crack initiation and crack growth are functions of stress level, number of cycles and the stress history (or sequence). Ideally the load information would provide a continuous load cycle history, but this is not practical for ships as one does not know a priori the sequence of ship operations (headings, speed etc) and sea conditions. It is therefore necessary to develop some approximate method of representing the stress amplitudes and cycles using the probabilistic load data as described in [20,21].

The ISSMM software will allow the user to identify the detail area of interest, automatically produce the appropriate FE model, allow the user to efficiently modify the structure to incorporate damage (including cracks) and automatically undertake a fatigue crack initiation or growth assessment for the chosen ship operation. The challenge for ISSMM will be to make what is a complex analysis, easily available to the user in a 'black-box' format without excessive loss of accuracy to the methods.

In addition to the stresses and strains and the stress intensity values in the region of a hot-spot or crack tip caused by the sea wave and still water loading, there are also built-in strains caused by the manufacturing process of the structure. Welding produces residual strains and fitting together of structural components produces restraint strains. Together these two effects, along with still water load strains, are termed the residential strains. It is planned that a residential strain atlas of the Halifax Class be developed using the Miniature X-Ray Diffraction (MXRD) system, developed by DREA and Proto Manufacturing [22].

Structural Component Stress and Stability Assessment

In addition to fatigue and ultimate strength failure modes, ISSMM will address the performance of individual ship structural components. Component evaluation follows traditional ship design practice where the ship is evaluated as individual components rather than a continuous structure. FEA of ship structures lends itself to the evaluation of continuous structure rather than individual components. Therefore, the finite elements and resultant stresses must be mapped to the particular component that they represent. The effects of damage on these components will be to either change the configuration of the component itself if it is directly damaged, or to change the load which is applied to the component as a result of redistribution of the load due to damage in adjacent structure. Strength and stability are the structural parameters which must be evaluated for each component.

Mission Risk Assessment

The user of ISSMM will enter the desired ship operation and the structural condition of the ship. The likely loads that the ship will see during that operation, the structural capacity of the intact ship and the effects of damage have to be evaluated and presented to the user in a meaningful manner.

Probabilistic or reliability methods of structural analysis are becoming accepted in structural engineering practice and are particularly useful in comparing the performance of two structural systems against a given load, particularly when that load is best described in statistical terms. A comparison of probabilities of failure between the damaged and undamaged cases will provide a tangible change in risk to the user. A deterministic evaluation can also be carried out using characteristic values of the load effects and resistance (such as the stress occurring in a panel from the finite element analysis versus the nominal yield stress of the material). It is beyond the scope of ISSMM to develop load and strength statistics other than by reviewing what has already been developed and determining acceptable values.

The results will be presented as a function of ship operation in a manner to allow the user to determine what operational conditions should be avoided. A means to repair the damage to different levels in the analysis models and determine the effects of these repairs on the risk will also be developed and implemented.

Concluding Remarks and Future Plans

This paper has given a brief overview of the plans and progress for the DND major project ISSMM for the structural integrity and operational risk assessment of Canadian Forces warships. ISSMM is taking a progressive approach to the definition of sealoads, structural analysis, risk assessment, and the data and program management structure. Developments undertaken as part of the concept development studies are being used by ship classification societies, and other Navies who have contributed funding to the further developments.

The next phase for ISSMM involves the combination of the analysis programs and data structures in a single computer tool. This will be done under prime contract which is expected to begin in mid 1999 for completion of version 1 in 2002.

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